Microbial Influenced Corrosion (MIC) Study

National Defense Industry Association Environment, Energy Security, & Sustainability Conference

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Jim Tankersley
Battelle

Paul Hoth
Hill AFB

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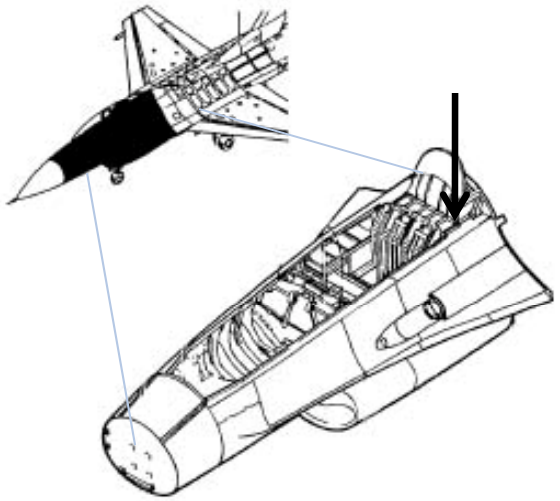
Overview

- Background
- Technical Approach
- Aircraft Sampling
- Microbial Characterization
- MIC Testing - Technical Approach
- Results of MIC Testing
- Mitigation Assessment
- Conclusions & Recommendations
- Overview of Current Project
- Points of Contact
- Questions

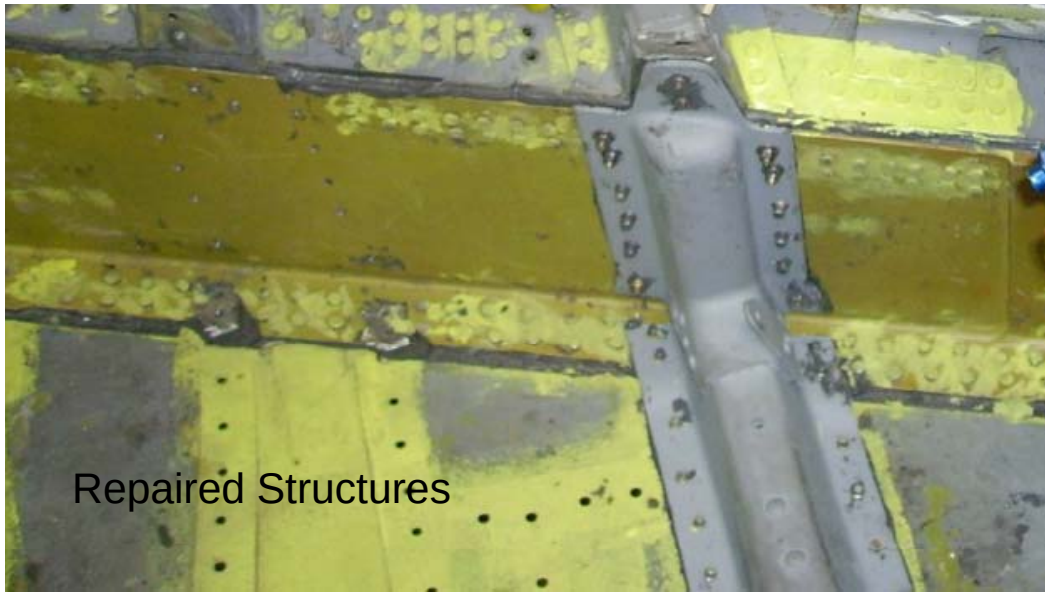
Background

- Moisture routinely enters aircraft in different ways
  - open canopy, condensation, high humidity, Environmental Control System or ECS, etc…
- Moisture is absorbed and retained within insulation blankets used to seal lower walls and floor,
- No drain holes in aft area to remove moisture (B/D variants),
- Water collects and retained in low lying areas breaks down protective coating system and causes structural corrosion,
- Water and organic/inorganic nutrients support microbial growth.



Background (cont…)

- Hill AFB representatives at World Wide Review for TCG countries stated that structural corrosion is a problem in most "B" and "D" models



Background (cont…)

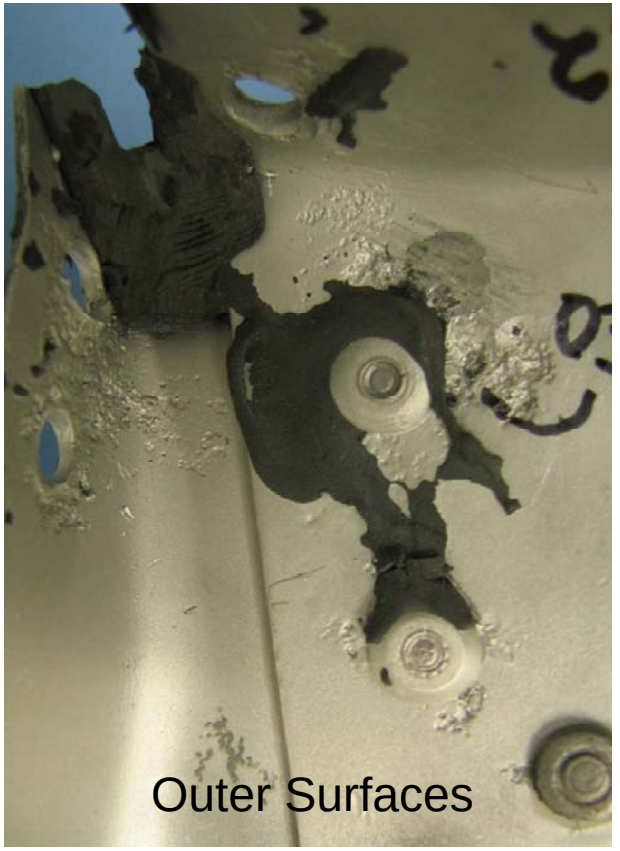
- Microbial contamination may exist in many areas within all types of military aircraft
- Microbial contamination is often not reported during field and depot-level maintenance operations

Background (cont…)

- Most damage confined to pitting corrosion of primary and secondary support structures
- Pitting corrosion morphology (i.e., tunneling suggests MIC)


Outer Surfaces


Inner Surfaces


Outer Surfaces

Microbial Influenced Corrosion Characterization and Prevention

(FY09-10 Project)

Technical Approach

- Work with client and stakeholder team to evaluate the potential for MIC of aircraft structures:
  - Collect and characterize microbial species from aircraft
  - Validate MIC damage mechanisms under environmental conditions expected within areas of aircraft
  - Identify and assess the effect of possible short- and long-term mitigation technologies:
    - Chemical disinfection (T.O 1-1-8 and T.O 1-1-691)
    - Biocidal rinses and coatings
    - Biocidal Corrosion Preventative Compounds or CPCs

Aircraft Sampling

Condemned Aircraft Component Parts

- Sixty-three samples collected from similar parts and OML locations (control samples) on six aircraft at Hill Air Force Base

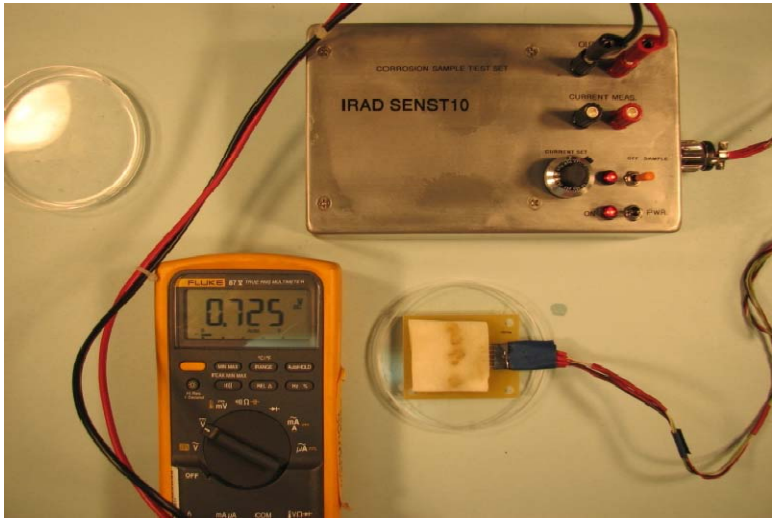
Microbial Isolates Recovered

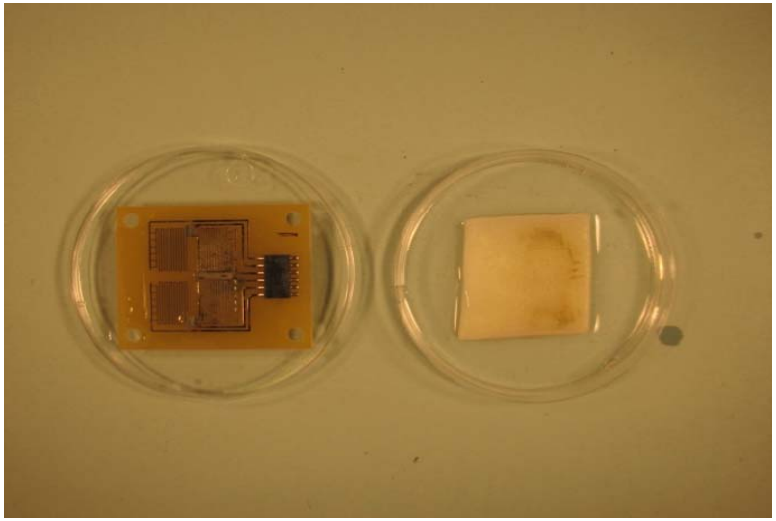
- Seventeen (17) different bacterial isolates and sixteen (16) fungal isolates recovered from the sixty-three surface samples collected from aircraft and nine off-aircraft component parts
- Compared microbial populations recovered from the aircraft and parts; looking for consistencies and differences of populations recovered from corroded versus non-corroded areas
- Compared microbial populations to MIC species reported in literature
- Coordinated observations, results, conclusions and recommendations with representatives from Hill AFB, the Air Force Research Laboratory (AFRL), and Naval Research Laboratory (NRL)

Test Matrix

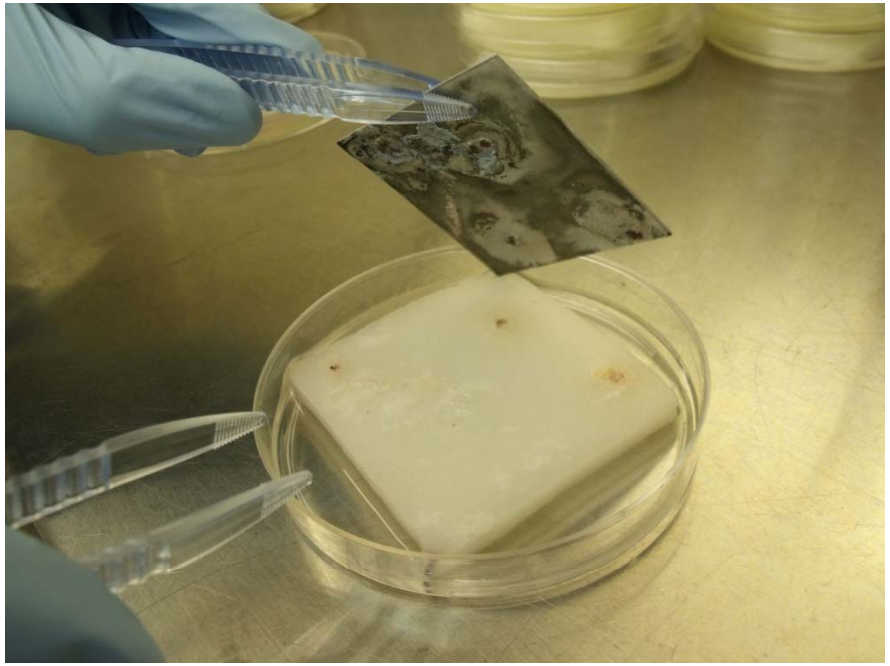
Parameter	Description
Coupon Type	2024-T3 aluminum alloy
Sensor Type	1020 low carbon steel
Incubation Conditions	26± 2C; 75-80% Rel. Humidity
Bacteria Consortium	*Microbacterium saperdae* *Rhodococcus equi* *Staphylococcus epidermidis*
Fungal Consortium	*Aspergillus fumigatus* *Fusarium oxysporum* *Penicillium oxalicum* *Rhodoturula sp.* *Trichoderma sp.*
Control Sensors and Coupons – Positive A	Dosed with microbes known to influence corrosion and used in a recent AFRL corrosion study: *Pseudomonas fluorescenscens* *Delftia acidovorans* *Enterobacter cloacae*
Control Sensors and Coupons – Positive B	Dosed with bleach, a corrosive agent
Control Sensors and Coupons – Negative	Dosed with buffer only (no microbes present)

Experimental Set-up



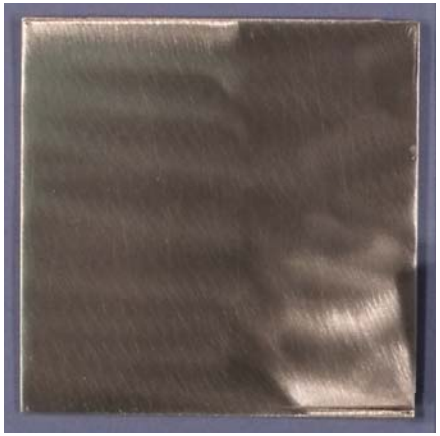


Battelle Corrosion Sensors

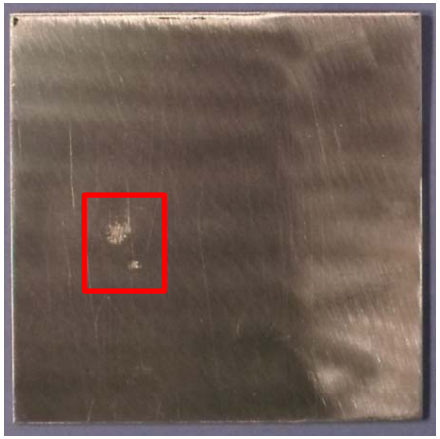


Weight-loss Coupons

Aluminum Coupon Results: 1-month Exposure, Chemically Descaled



Bacteria Consortia



Fungi Consortia

Combination

Buffer Only

Aluminum Coupon Results: 2-month Exposure, Descaled

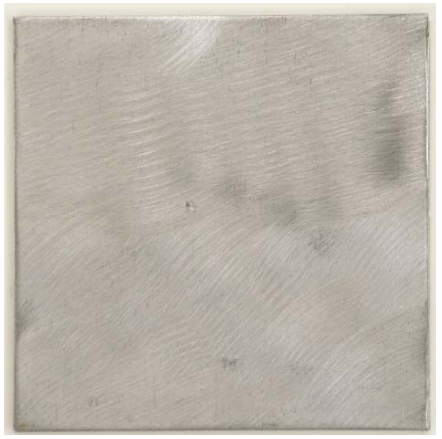
Top

Bacteria Consortia

Fungi Consortia

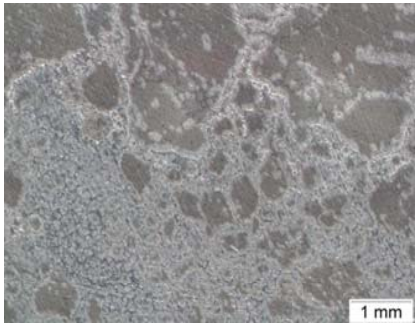
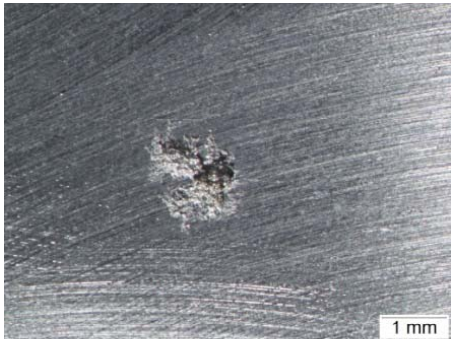
Combination

Buffer Only



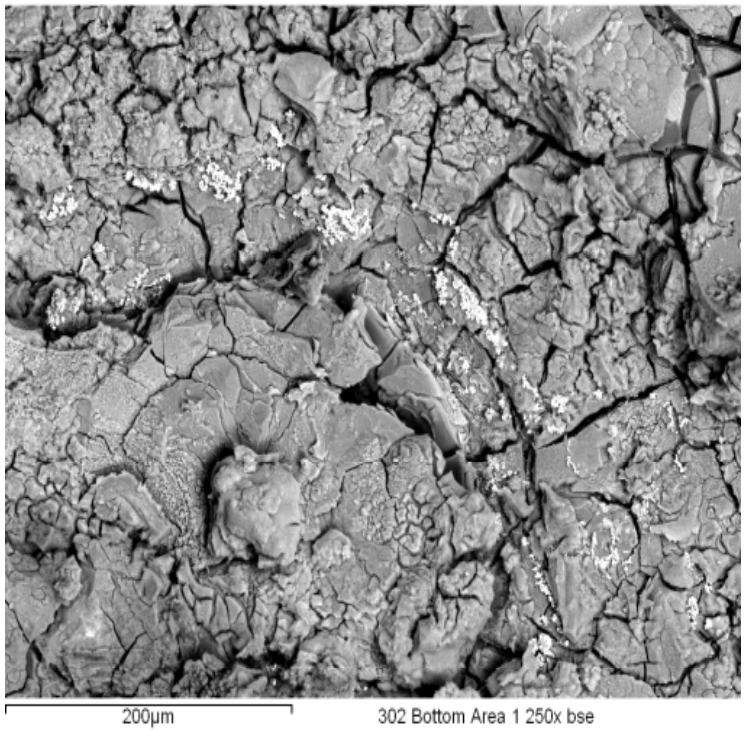
Bottom

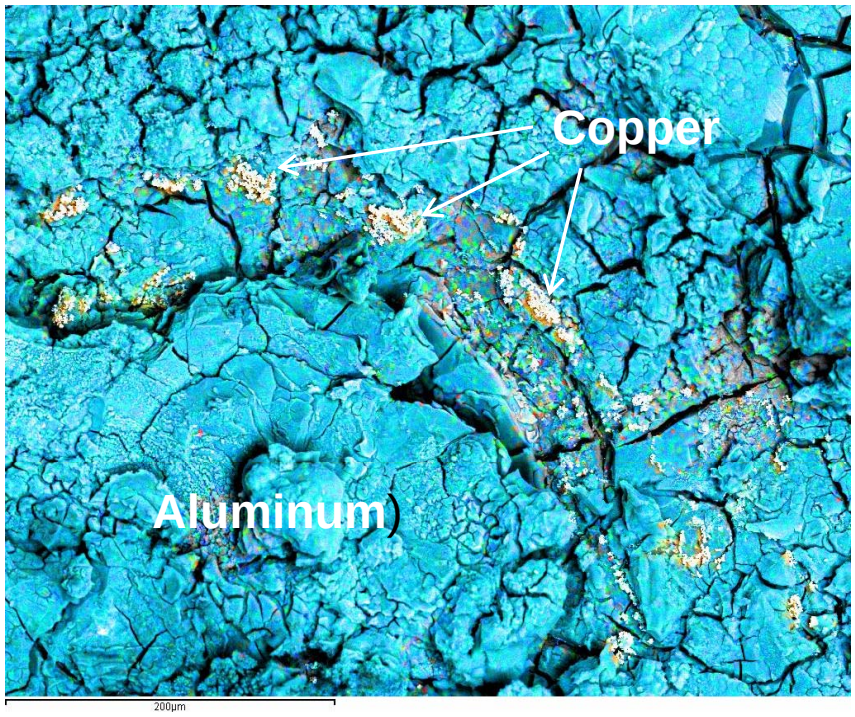
Al Coupon Results: 3 Month Exposure, Descaled - Optical Micrographs

	Bacteria Consortia	Fungi Consortia	Combination	Buffer Only
Top				
Bottom		 	 	

Aluminum Coupon Results: 3 Month Exposure, Cleaned (Representative Samples)

Coupon ID 302 Bacteria Consortia

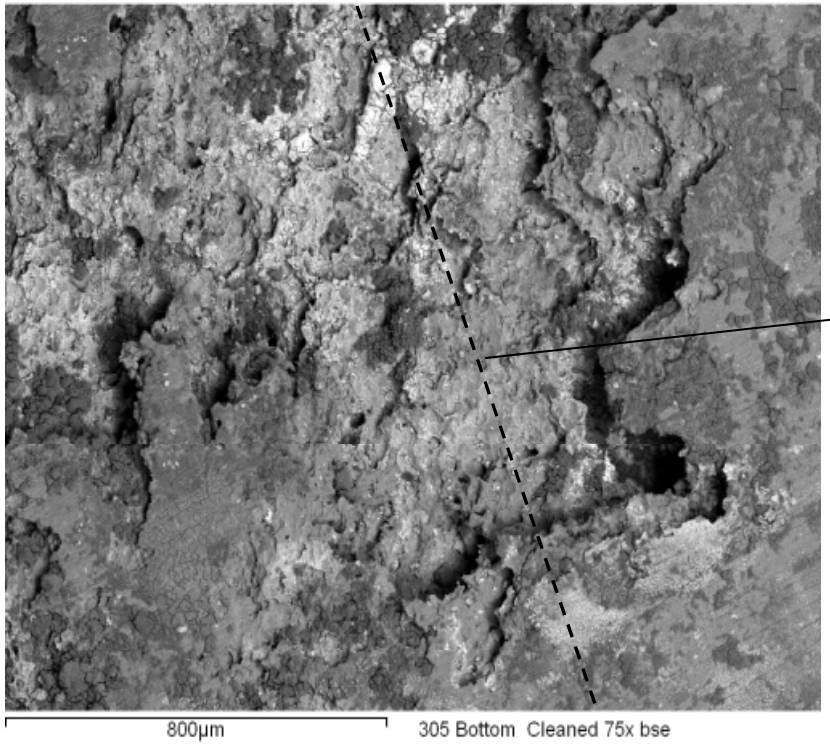


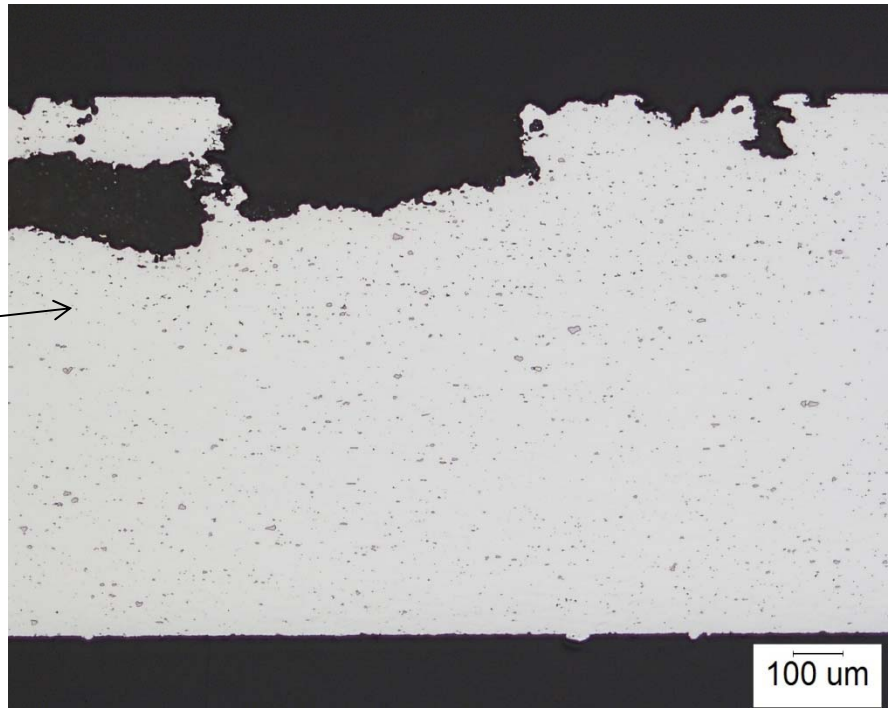


Dried biofilm and corrosion products inside pit area, with evidence of selective metal ion extraction or dealloying from metal or alloying networks

Aluminum Coupon Results: 3 Month Exposure, Descaled (Representative Samples)

Coupon ID 305 Fungi Consortia





Aluminum Coupon Results: 3-month exposure

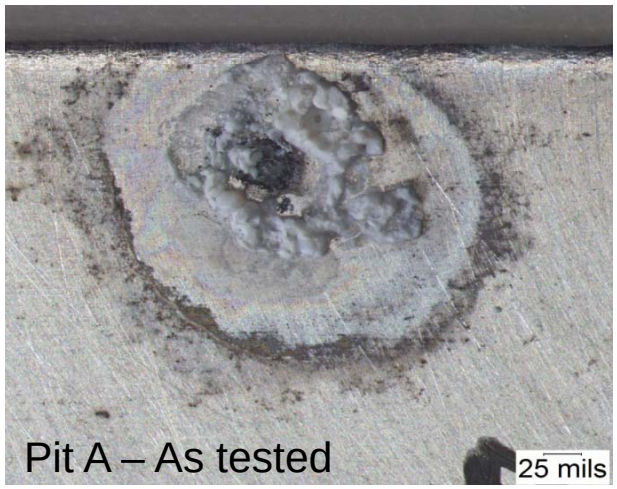
Legend

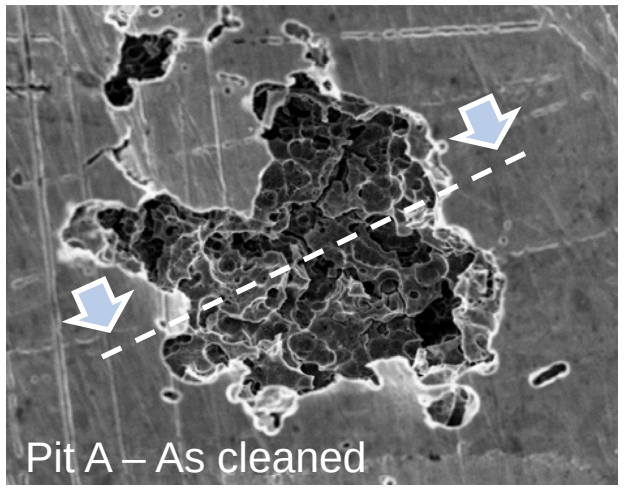
B Bottom
G General
L Localized
NP No pitting
P Pitting
T Top
X # of Pits

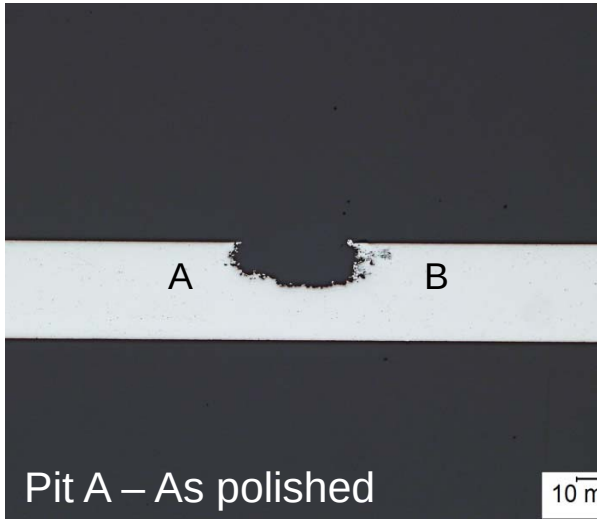
Coupon ID	Test Solution	pH	Discoloration Top	Discoloration Bottom	Pitting, max (mils)	Comments
701	Buffer only	7	3L-NP	G-NP	~5 T	General staining only – T/B
702	Buffer only	7	None	E-1P	~3 B	1 area of localized pitting - B
703	Buffer only	7	1G-3P	G-NP	~2 T	General staining only – T/B
704	Buffer only	7	None	3L-1P	<5 B	Localized staining – B only
705	Buffer only	7	None	None	0	No staining detected – T/B
706	Buffer + Biocide	5.5	2L-1P	2L-1P	~1 B/3 T	Localized staining only – T/B
707	Buffer + Biocide	5.5	2L-1P	1L-1P	~1 T/B	Localized staining only – T/B
708	Buffer + Biocide	5.5	2L-1P	G-NP	~3 T	Localize staining only – T/B
709	Buffer + Biocide	5.5	2L-NP	1L-1P	~5 B	Localized staining/etching – T/B
710	Buffer + Biocide	5.5	4L-NP	G-1P	~1 B	Localized staining – T/B
711	Water only	5.5	None	None	0	No staining detected – T/B
712	Water only	5.5	None	None	0	No staining detected – T/B
713	Water only	5.5	None	1L-1P	~1 B	Localized staining – B only
714	Water only	5.5	None	None	0	No staining detected – T/B
715	Water only	5.5	None	None	0	No staining detected – T/B
716	Fungal Consortia	7.5	3L-1P	G-NP	>6 T	Surface staining – B only
717	Fungal Consortia	7.5	4L-4P	G-NP	>12 T	Surface staining/localized pitting on T surfaces only
718	Fungal Consortia	7.5	1L-1P	G-NP	>20 T	Edge corrosion – T only
719	Fungal Consortia	7.5	3L-1P	G-NP	<1 T	Surface staining – T/B
720	Fungal Consortia	7.5	G-NP	None	0	No staining detected – T/B
721	Aircraft Consortia	7.5	G-2P	G-5P	>15 B	Edge corrosion pits – B deepest
722	Aircraft Consortia	7.5	22L-2P	G-NP	~15 T	Edge corrosion pits – T deepest
723	Aircraft Consortia	7.5	3L-3P	4L-4P	~10 T	Edge corrosion pits – T deepest
724	Aircraft Consortia	7.5	1L-1P	G-NP	~10 T	Edge corrosion pits – T deepest
725	Aircraft Consortia	7.5	5L-5P	G-1P	>30 T/B	Edge thru-wall penetration

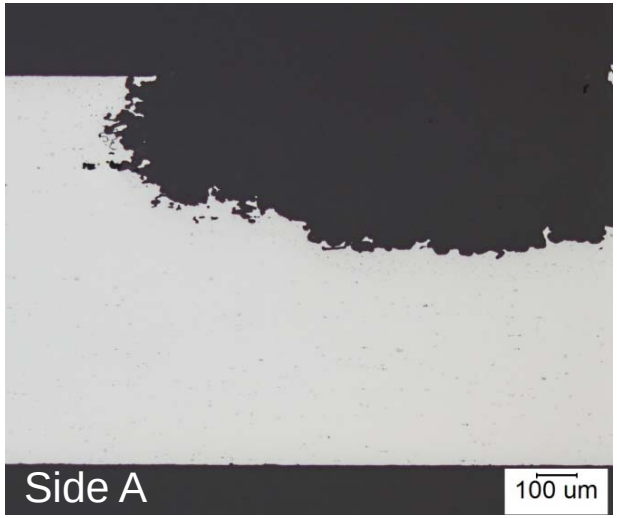
Aluminum Coupon Results: 3-month Exposure (Representative Sample)

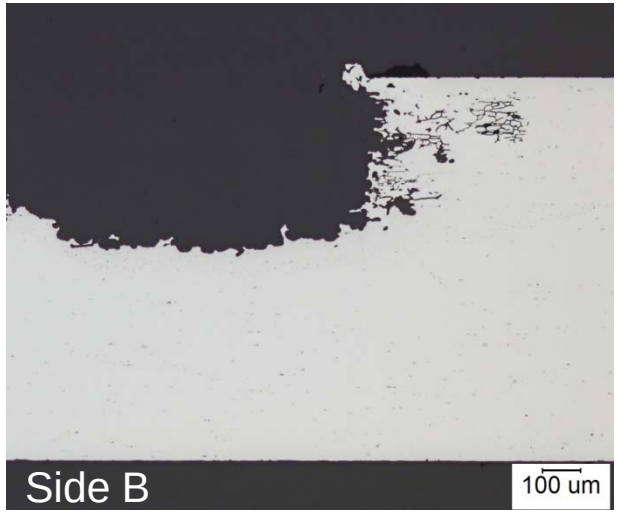
Coupon ID No. 722 (Aircraft Consortia)





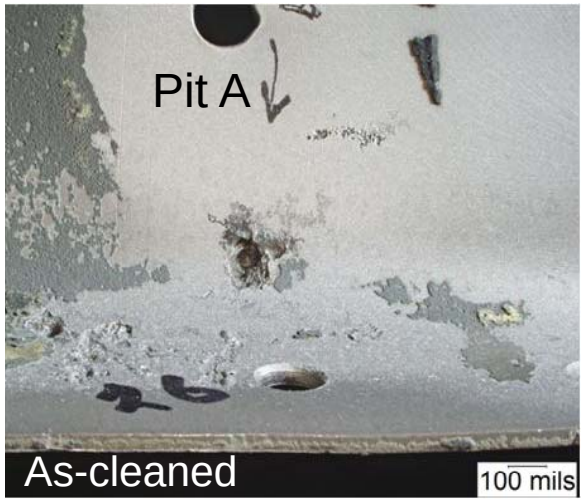


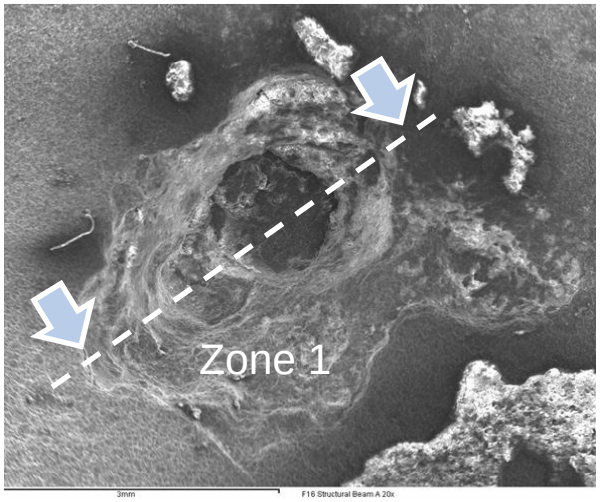


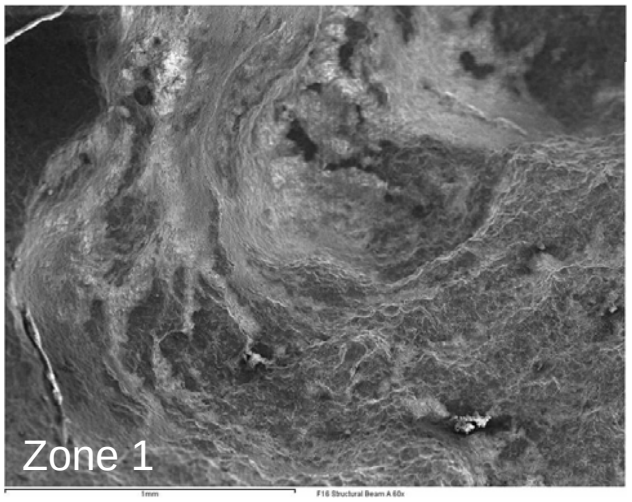


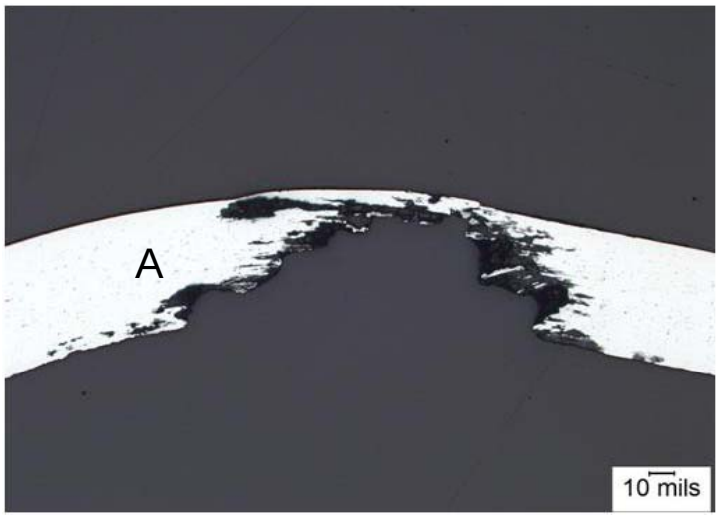
Aluminum Parts Results: In-Service Exposure (Representative Sample)

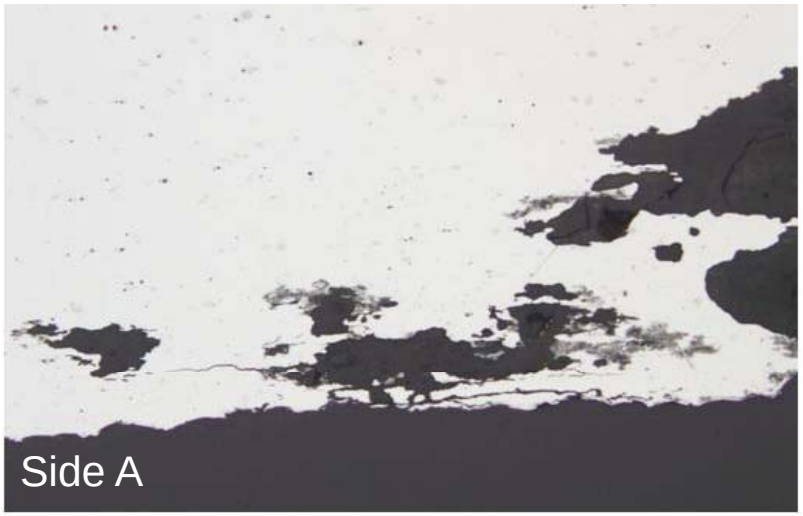
Aircraft Beam











MIC Cr^{+6} Mitigation Assessment: Technical Approach

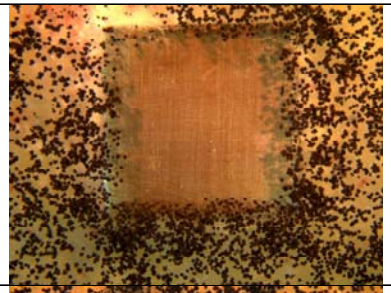
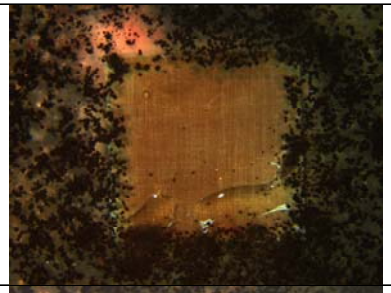
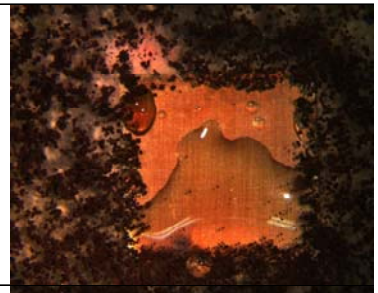
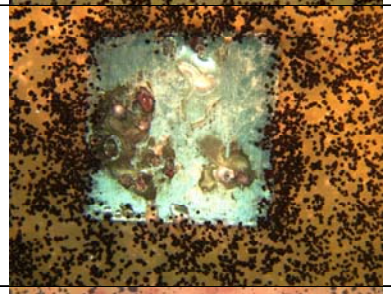
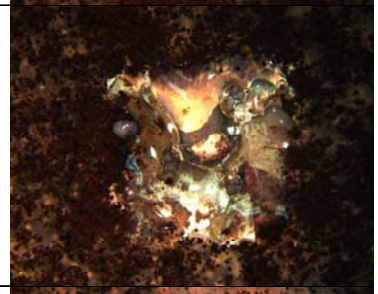
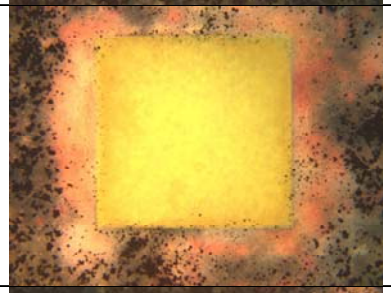
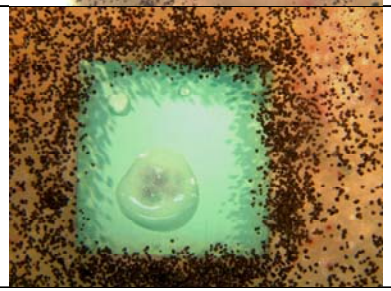
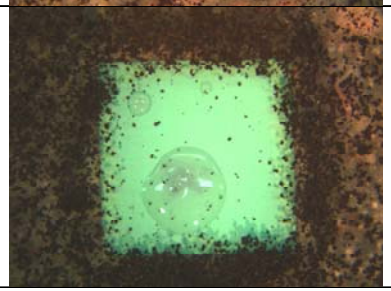
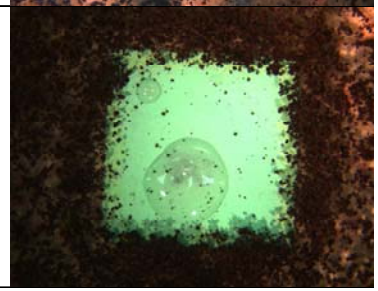
- **ASTM Test Methods**
  - E 2180-07: Standard Test Method for Determining the Activity of Incorporated Antimicrobial Agent(s) in Polymeric or Hydrophobic Materials
  - D 5590-00 (Reapproved 2005): Standard Test Method for Determining the Resistance of Paint Films and Related Coatings to Fungal Defacement by Accelerated Four-Week Agar Plate Assay
  - D 3274-09: Standard Test Method for Evaluating Degree of Surface Disfigurement of Paint Films by Fungal or Algal Growth, or Soil and Dirt Accumulation
- **Fungal Consortium**
  - *Aspergillus sp* (FI-19)
  - *Fusarium oxysporum* (FI-6)
  - *Hypocrea jecorina (FI*-1)
  - *Pleosporacea sp*. (FI-17)
  - *Ustilago maydis* (FI-13)
  - *Aureobasidium pullulans* (FI-16)
  - *Fusarium sp*. (FI-18)
  - *Penicillium oxalicum* (FI-12)
  - *Rhodoturala mucilaginosa* (FI-7)
- **Test Systems**

Test System	Description
A	Coupons on acidified Potato Dextrose Agar (aPDA); variation of ASTM D5590-00
B	Coupons on Agar slurry inoculum overlay; variation of ASTM E 2180-07
C	Coupon Suspension Test

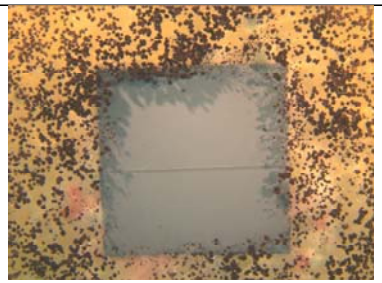
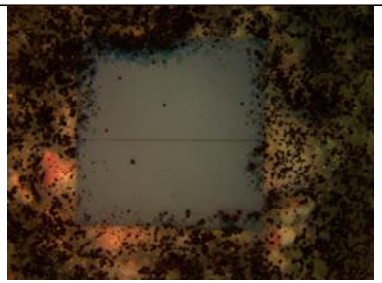
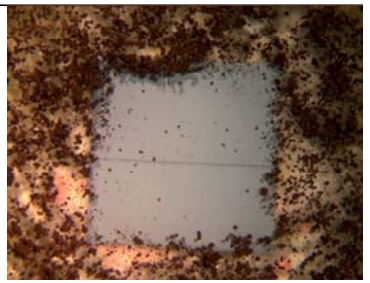
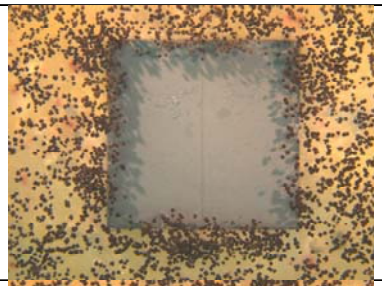
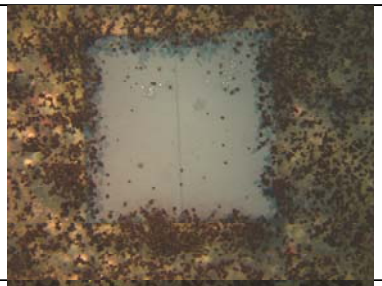
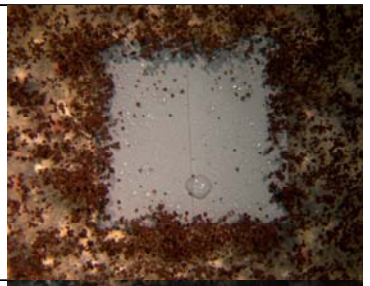
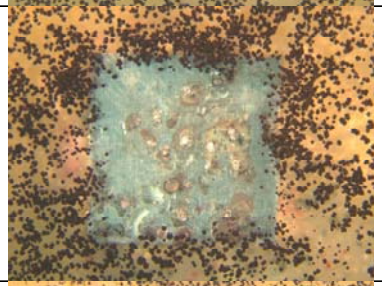
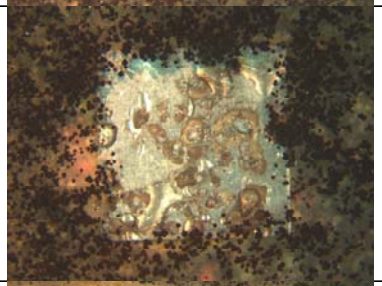
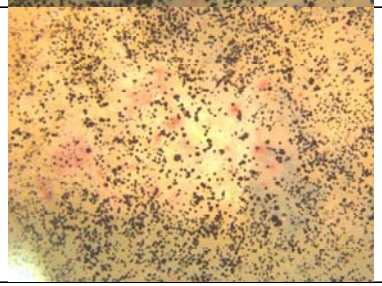
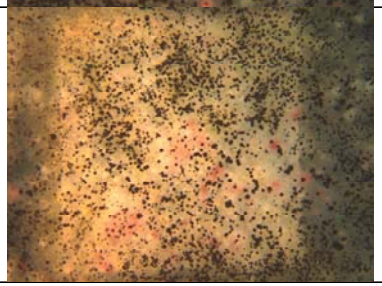
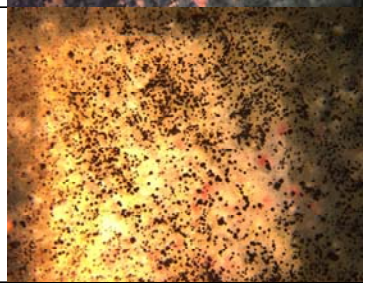
MIC Cr^{+6} Mitigation Assessment: Test Matrix

Sample Type	Sample Group	Sample Numbers	Description
Test	1	1-3	Cr^{+6} conversion coating applied to coupons spiked with fungal consortium
	2	4-6	Non-Cr^{+6} treatment applied to coupons spiked with fungal consortium
	3	7-9	Cr^{+6} conversion coating and Cr^{+6} primer applied to coupons spiked with fungal consortium
	4	10-12	Non-Cr^{+6} treatment and Non-Cr^{+6} primer applied to coupons spiked with fungal consortium
	5	13-15	Cr^{+6} conversion coating and Cr^{+6} primer and topcoat applied to coupons spiked with fungal consortium
	6	16-18	Non-Cr^{+6} conversion coating and Non-Cr^{+6} primer and topcoat applied to coupons spiked with fungal consortium
	7	19-21	Uncoated coupons spiked with fungal consortium
Positive Matrix Controls	8	22-24	Whatman #2 filter paper spiked with fungal consortium
Negative Matrix Controls	9	25-27	Cr^{+6} coated coupons; spiked with sterile water
	10	28-30	Non-Cr^{+6} coated coupons; spiked with sterile water
	11	31-33	Uncoated coupons; spiked with sterile water
	12	34-36	Whatman #2 filter paper; spiked with sterile water
Positive Antifungal Control	13	37-39	Coupons coated with a known antifungal (TBD)

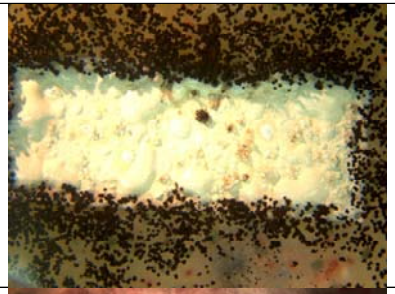
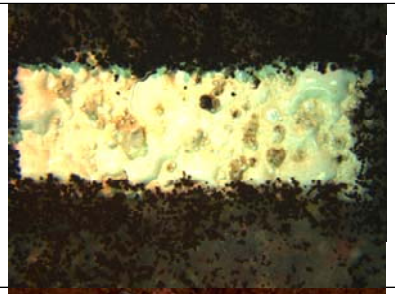
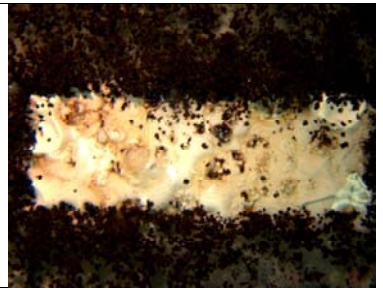
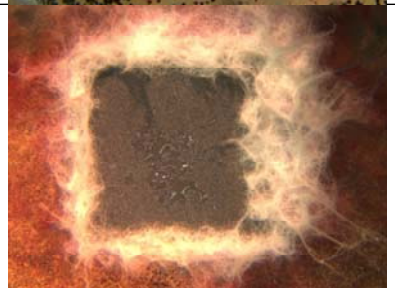
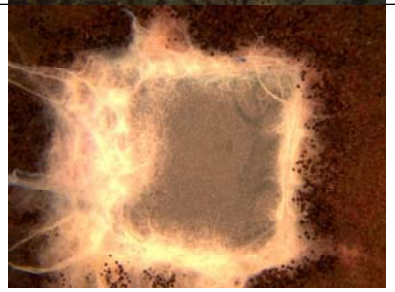
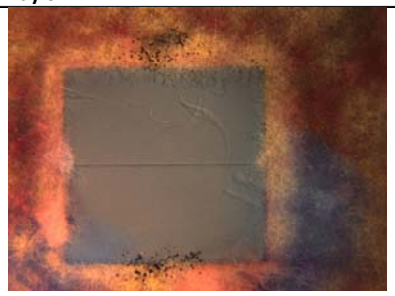
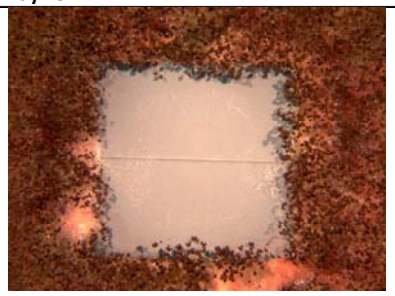
MIC Cr^{+6} Mitigation Assessment: 4-week Exposure Results

Coupon Type	SYSTEM I: Treated – aPDA + fungal consortium (coupon laying on fungi treated agar media) DAY 8	DAY 14	DAY 28
Chrome Conversion Coating Coupon Type: A *Alodine 1200 (Henkel)*			
Non-Chrome Treatment Coupon Type: E *Prekote® (Pantheon Chemical)*			
Chrome Conversion Coating + Chrome Primer Coupon Type: B *Alodine 1200 (Henkel) MIL-PRF-23377H, TY 1, CL 2 (Deft - 02Y040A)*			
Non-Chrome Treatment + Non-Chrome Primer Coupon Type: F *Prekote® (Pantheon Chemical) MIL-PRF-23377H, TY 1, CL N (Deft – 02GN083)*			

MIC Cr^{+6} Mitigation Assessment: 4-week Exposure Results

	SYSTEM I: Treated – aPDA + fungal consortium (coupon laying on fungi treated agar media)		
Coupon Type	**DAY 8**	**DAY 14**	**DAY 28**
Chrome Conversion Coating + Chrome Primer + Topcoat Coupon Type: C *Alodine 1200 (Henkel)* *MIL-PRF-23377H, TY 1, CL 2 (Deft – 02Y04A)* *MIL-PRF-85285D, TY 4, CL H (Deft – 99GY001)*			
Non-Chrome Treatment + Non-Chrome Primer + Topcoat Coupon Type: G *Prekote® (Pantheon Chemical)* *MIL-PRF-23377H, TY 1, CL N (Deft – 02GN083)* *MIL-PRF-85285D, TY 4, CL H (Deft – 99GN001)*			
Uncoated Coupon Type: D *Bare Al2024-T3* *(Negative Control)*			
Whatman Paper *(Positive Control)*			

MIC Cr^{+6} Mitigation Assessment: Exposure Results

	SYSTEM I: Treated – aPDA + fungal consortium (coupon laying on fungi treated agar media)		
Coupon Type	**DAY 6**	**DAY 13**	**DAY 28**
Bunge Silver Coating Coupon Type: H *Proprietary Coating w/ Silver Inhibitor*			
Non-Chrome Treatment + Mg-Rich Primer Coupon Type: I *Prekote® (Pantheon Chemical) Aerodur 2100 (Akzo Nobel Aerospace)*	 **Day 6**	 **Day 13**	N/A
Non-Chrome Treatment + Mg-Rich Primer + Topcoat Coupon Type: J *Prekote® (Pantheon Chemical) Aerodur 2100 (Akzo Nobel Aerospace)* *MIL-PRF-85285D, TY 4, CL H (Deft – 99GY001)*	 **Day 6**	 **Day 13**	N/A

Conclusions

- 17 bacterial & 16 fungal species (common environmental isolates)
  - Minimal impact to health & safety
- Fungal species promote MIC of Al2024-T3 alloy
- Intergranular attack with selective metal ion extraction mode of corrosion damage
- Hexavalent chromium has limited biocidal effect on specific fungal species
- Age and condition of chromated primer "controls" resistance to MIC on 2024-T3 aluminum alloy

Evaluation of Antimicrobial Compounds and Their Effects on MIC

(FY11-12 Project)

Scope

- To continue all ongoing comparative assessments of hexavalent chromium containing primers and non-chromated primers being investigated by the United States Air Force
- To evaluate antimicrobial compounds with broad spectrum inhibition properties blended into a water rinse and applied directly to outer moldline (OML) surfaces of an aircraft
- To evaluate antimicrobial compounds with broad spectrum inhibition properties blended into a commercial coating or thin corrosion preventative compound (CPC) and directly applied to the inner moldline (IML) surfaces of an aircraft
- To measure and evaluate in the laboratory the contribution of MIC processes to crevice corrosion that are occurring on aircraft structures

Technical Approach & Teaming

- **Task 1.0 Assessment of MIC with Chromated and Non-chromated Treatments and Biocidal Coatings**

  Battelle – formulate biocidal coatings, prepare all test panel sets, and provide required panel testing and data analysis

  NRL – assist Battelle with an analysis of results and microscopic characterization of fungal growth

- **Task 2.0 Formulate and Evaluate Biocidal Rinse Water Solutions**

  Battelle – prepare all test panel sets, assist in the down-selection, formulate biocidal rinse solutions; conduct visual and microscopic assessments of panels

  NRL – analyze and microscopically (SEM) characterize test panel surfaces

  CP&S – assist in the selection and formulation of commercial biocides

Technical Approach & Teaming

- **Task 3.0 Formulate and Evaluate CPCs Containing Biocides**

  Battelle – prepare test panels, measure and validate the beneficial effects of CPCs containing biocides through an elimination of fungal growth and reduction of coating degradation

  NRL – provide consulting services, assist with analysis of test data, and conduct microscopic characterization of "as-tested" surfaces of designated panels

  CP&S – provide support with the down-selection and formulation of biocidal CPC materials

- **Task 4.0 Investigate MIC Processes and Effects on Crevice Corrosion**

  NRL – measure and validate the contribution of MIC processes to crevice corrosion

  SwRI – conduct a controlled laboratory corrosion assessment of MIC and anti-microbial activities on the surfaces of Al2024-T3 test panels

  Battelle – prepare test panel sets and provide technical support on an "as-required" basis

Points of Contact

Mr. John Stropki

Battelle Columbus Operations

(614) 424-5414

stropki@battelle.org

Mr. Paul Hoth

Hill AFB, UT

(801) 775-4889

paul.hoth@hill.af.mil

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Questions??

Thank you!